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Evaluation of Continuous Monitoring Systems for Pressurized Baghouses

Engineering-Science, Inc.
Durham, NC

Prepared for

Environmental Protection Agency
Chicago, IL

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Evaluation of Continuous Monitoring Systems for Pressurized Baghouses

March 1981

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Air Enforcement Branch
230 South Dearborn Street
Chicago, Illinois 60604

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Pressurized baghouses (PB) are frequently used in large systems for controlling particulate discharges. Preliminary tests indicate that there is striation of the gas streams in baghouse cells, so some equipment failures may not be registered by continuous opacity monitoring (COM) equipment. Reliable monitoring depends on a representative gas stream passing the COM beam, but significant equipment failure can exist with discharge opacity less than 3%. Many existing systems could be modified to provide gas blending. Equipment exists which can detect particulate loading far below the 3% opacity level, but this equipment does not relate directly to opacity. Parameters necessary for a successful COM installation in a PB are: the gas stream must be blended; the COM beam must not exceed 100 feet; the COM output must be expanded so that 3% opacity covers a reasonable portion of the scale; path-length corrections should be permitted only where there is a difference in measured path length and discharge path length; and the COM beam should not be affected by external climatic effects.

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EVALUATION OF

CONTINUOUS MONITORING SYSTEMS FOR

PRESSURIZED BAGHOUSES

March 1981

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EVALUATION OF CONTINUOUS MONITORING SYSTEMS FOR PRESSURIZED BAGHOUSES

INTRODUCTION

This study, initiated in response to Task Order 62 of Contract 68-01-4146, is intended to determine the conditions which must be met to ensure successful installation of a continuous opacity monitor (COM) at a pressurized baghouse (PB).

Baghouses are efficient devices for removing particulate matter from discharge gas streams. Gas is drawn or blown through the bags which are usually contained in individual cells. Figure 1 diagrams a negative pressure baghouse; Figure 2 diagrams a pressurized baghouse. The PB does not require dampers on the discharge side of each cell to isolate the cells for cleaning, and it does not require ductwork at the discharge side to connect to the blower. For large installations, the cost differential can be considerable. Commonly, PB installations are used in the ferrous and nonferrous industries, and are almost universally used as a method of particulate control for emissions from electric arc furnaces.

Properly designed, well-maintained baghouses can maintain low discharge particulate levels with gas opacities approaching zero. Sudden bag failure can occur for a number of reasons:

- Hot particles can burn holes in one or several bags,
- Hot gas can cause failure of many or all bags,
- Sharp-edged material may tear the bags,
- Normal operation may wear the bags, causing tears or holes,
- Improper installation may allow gas to bypass the bags, or may permit a bag to come loose, and
- Corrosion or erosion may cause structural failure, permitting gas to bypass the bags.

Many of these failures were observed during plant visits (Appendix A).

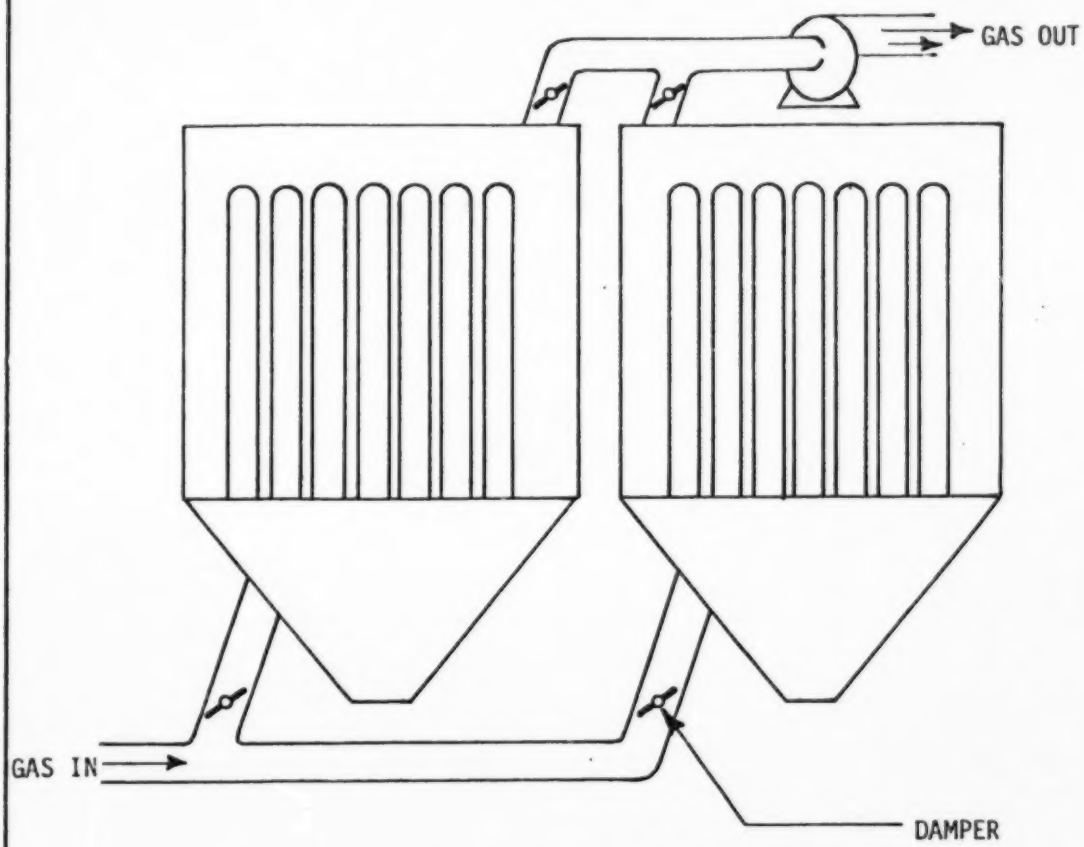

Figure 1. Negative pressure baghouse.

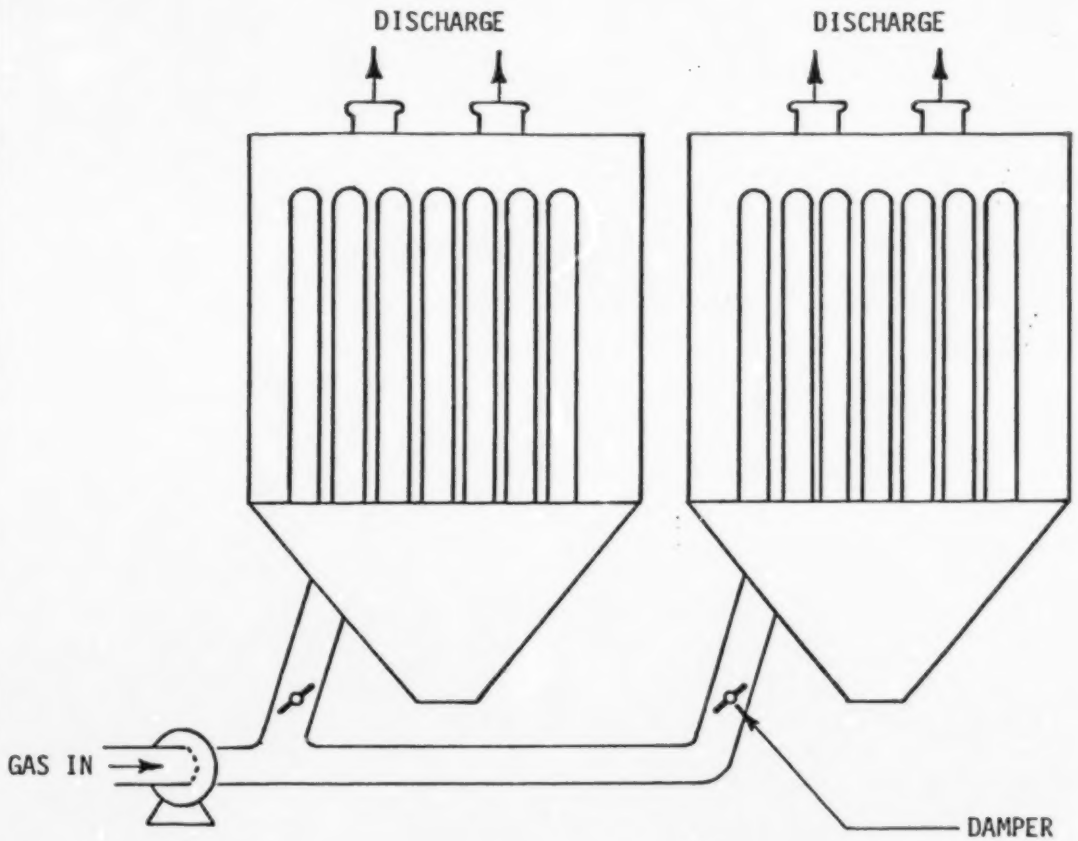

Figure 2. Positive pressure baghouse.

Federal regulations frequently require that baghouses be equipped with COM's to monitor opacity of the discharge gas stream. For example, 40 CFR 60, subpart AA (par. 60.270 et seq) requires installation of a COM, and defines excess emissions as "all six minute periods during which the average opacity is 3 percent or greater."

This report reviews problems connected with the capabilities of existing COM equipment to reliably indicate discharge opacity from PB systems. Contacts were initiated, and visits were made to a trade association, to PB manufacturers, to COM manufacturers, and to plant sites.

BAGHOUSE CYCLES

Large PB installations usually consist of several cells arranged in one or several rows. A cell may be onstream for 1 or more hours before cleaning. Each cell is cleaned in sequence, usually on a fixed time cycle. Occasionally, a high pressure drop across the bags is used to initiate the cleaning cycle. Cleaning cycles vary, but usually last for 1 to 2 minutes, during which the bags are either shaken or subjected to pulses of reverse air. The dust from the bags settles into the bottom hoppers, and the cell is returned to service.

During the cleaning cycle, some dust may be emitted. When a cell is first returned to service, opacities of 20% to 50% may be observed for 15 to 20 seconds. Many COM systems include means to average discharge opacity during 6-minute periods, in accordance with regulations. One system was set to alarm only if 3% opacity was exceeded continuously for 6 minutes. Although this system avoided alarms arising from cleaning cycles, it also avoided many alarms which could arise from equipment failure.

CONTINUOUS OPACITY MONITOR INSTALLATIONS

Continuous opacity monitors were originally developed for control of emissions from stacks. Opacity was controlled at 20%, and path length rarely exceeded 35 feet. The light frequency range of the COM was set in the "photopic" range to correlate monitor readings with visible readings by a trained observer. Performance specifications for these systems are contained in 40 CRF 60, Appendix B.

The path lengths of existing COM systems are limited by three interrelated phenomena:

- Light from the transmitter is emitted in the form of a cone. Increase in path length increases the base of the cone, so light energy incident on the photocell is inversely related to the square of the path length.
- Each electronic system has some internal noise. As light energy on the photocell decreases, capability to differentiate incident light levels decreases because output signals fall into the system noise range.
- Photopic light sources originate from incandescent lamps. Higher output lamps have shorter life and less stable light output.

Only four of the nine COM manufacturers contacted by ES offered equipment which might be suitable for the long-path requirements of PB systems:

- Dynatron,
- Contraves,
- Lear Siegler, and
- Datatest.

All of the manufacturers contacted who were interested in supplying long-path COM equipment expressed the belief that the maximum path length will be about 100 feet for photopic systems. The longest path COM system which ES could locate was 65 feet.

Only one supplier produces a nonphotopic (laser-based) COM, but this system does not meet the requirements of 40 CFR 60, Appendix B. All manufacturers agree that a laser system, combining high-energy output with a narrow-angle light beam, should be a satisfactory long-path COM (although some questioned the reliability of laser systems). It would detect changes in opacity, but it might not relate to visible opacity measurements.

If currently available COM equipment is used, more than one unit will be needed to cover paths longer than 75 to 100 feet. These units may be placed in series or back to back.

Recorder Output

The 40 CFR 60, Appendix B (par. 4.3) specifies that the system output shall permit expanded display of the span opacity on a 0% to 100% scale. Since the prime COM market is for stack installations, standard units are equipped with 0% to 100% charts. It is impossible to differentiate low-level

opacities (0% to 5%) on these charts. If the charts are to be used as an enforcement tool, a different scale, perhaps 0% to 20%, should be required. In addition, the source should be required to relate periods of excess emissions with steps taken to prevent such emissions.

Calibration

Available COM systems periodically check themselves for zero setting and 100% span. Existing performance specifications permit zero drift of 2% opacity in 24 hours. This is not significant when high opacity levels are being considered, but it is critical when 3% opacity is the control level. Provision should be made for periodically verifying that the COM system is accurate at the alarm level; this would also permit verification that installed system alarms are activated when the equivalent average 6-minute opacity is 3% or greater.

Equivalent Path Length

Gases from PB systems are frequently discharged from multiple openings or from significantly nonround openings; two such systems are discussed. In a system with eleven 3' x 2' stacks, the total area is

$$3' \times 2' \times 11 = 66 \text{ ft}^2.$$

If the optical path is across the 3-foot stack dimension, the total path length would be

$$3' \times 11 = 33 \text{ ft.}$$

A 9-foot diameter duct has a similar cross section (64 ft^2).

Appendix B of 40 CFR 60 (par. 4.3) gives a path-length correction:

$$\log(1 - O_1) = L_1/L_2 \log(1 - O_2)$$

where O_1 = opacity of effluent based on L_1,

O_2 = opacity of effluent based on L_2,

L_1 = the emission outlet path length, and

L_2 = the monitor path length.

Substituting in this equation

$$\log(1 - .03) = 9/33 \log(1 - O_2),$$

$$1 - O_2 = 0.894$$

$$O_2 = 0.105 = 11\%$$

If the COM is set to indicate opacity of the multiple discharges corrected to a single equivalent duct, opacity of gas in the COM light beam would have to be almost 11% to register 3% opacity at the COM output.

Failure in one cell of an installation would cause high-opacity conditions only in the discharge from that cell. If the COM is set to average all stack discharges, the correction would be

$$\log(1 - 0.3) = 1/11 \log(1 - O_2)$$

$$1 - O_2 = 0.715$$

$$O_2 = 0.284 = 28\%$$

Thus, opacity in a single cell would have to reach 28% before the COM would indicate 3% opacity.

Path-length corrections were included in the electronics of all of the COM systems which were inspected, but it was not possible by inspection to determine the specific correction for any given system.

Baghouse Design

Of the various PB designs which have been produced, many of them are one of a kind, and many are of limited production. It was not possible to inspect all designs in the limited time available, but it was possible to broadly categorize PB's by bag-cleaning mechanism and by discharge arrangement.

The two main bag-cleaning mechanisms are mechanical shakers and reverse air. Shakers or rappers are connected to the top of the bags. When the cleaning cycle is initiated, flow of air to a cell is interrupted by the damper at the inlet duct (Figure 2), and the tops of the bags are vibrated for about a minute by a mechanical system. Dust falls into the hoppers under each cell; then the damper is opened to return the cell to service.

Reverse-air systems have a similar cycle, but each bag is internally supported by a steel helix. When the inlet damper closes, a damper in an auxiliary duct opens and connects the cell to a blower which sucks reverse air through the bags. The dust cake pulled from the inner bag walls falls into the hopper from which it is removed mechanically.

Neither of these cleaning methods significantly affects gas monitoring, but both cell and discharge arrangements directly affect COM measurements.

Generally cells are arranged in rows. Whether one or several rows of cells are used is determined by cell size, gas flow, and space availability.

A design consisting of multiple cells with top-center discharge (Figure 3) is frequently seen, but many other designs are in use. Figure 4 shows a vertical side-discharge. Figure 5 is a horizontal side-discharge. Figure 6 is a peak discharge.

Location of Monitor

It is current practice to install one COM for each row of cells if the light path is not too long, but this practice may permit discharge of particulate-laden gas which does not cross the COM path.

The COM's installed in a row of stacks, as shown in Figure 7, are subject to atmospheric effects such as fog, heavy rain, and fugitive dust. An installation of the type shown in Figure 8 might not be affected by particulates originating from a failure near either sidewall.

Gas Flow

Common to all baghouses which were inspected was the fact that gas was not mixed in the baghouse. This fact was verified by visual inspections of bag failures (Appendix A) and by photographs of discharges from smoke candles released from various locations in several baghouses. The photographs (Figures 9 to 12) clearly demonstrate that smoke travels in distinct striae from smoke candles to the baghouse discharge. There is no location where a COM light beam can be certain to intersect all high opacity events. Addition of more COM's would enhance the probability of "seeing" all events, but it would be difficult to be certain that all high opacity events would be registered without installing several COM systems at each row of cells.

It would be necessary to blend the gas stream to be sure that some particulates from a baghouse failure pass the COM beam. Even if this were done, visual inspection indicates that significant failures can exist with discharge opacity below 3%.

SUMMARY OF PROBLEMS

The essential problem of effective COM installations on PBs is the possibility that striae of gas containing heavy loadings of particulates will not

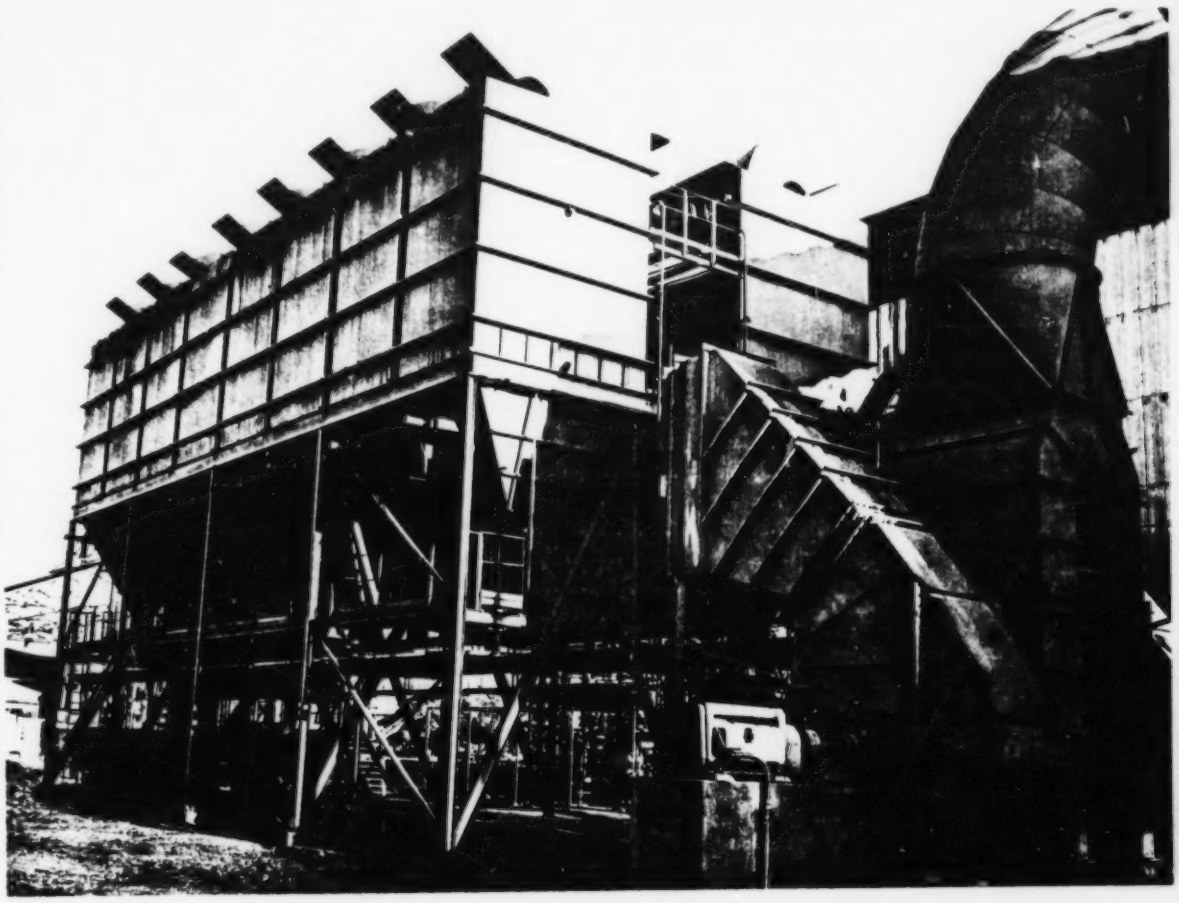

Figure 3. Multistack baghouse with top-center discharge.

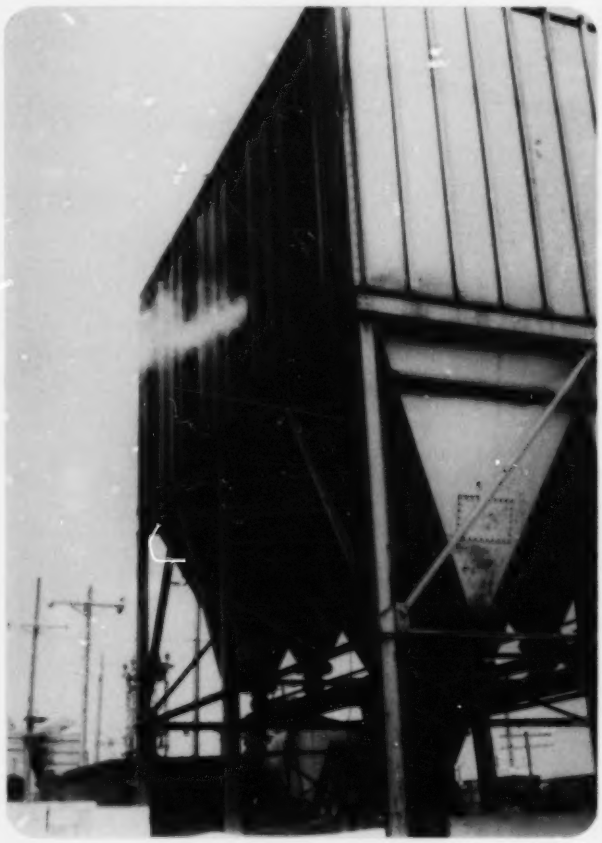

Figure 4. Multistack baghouse with vertical side-discharge.

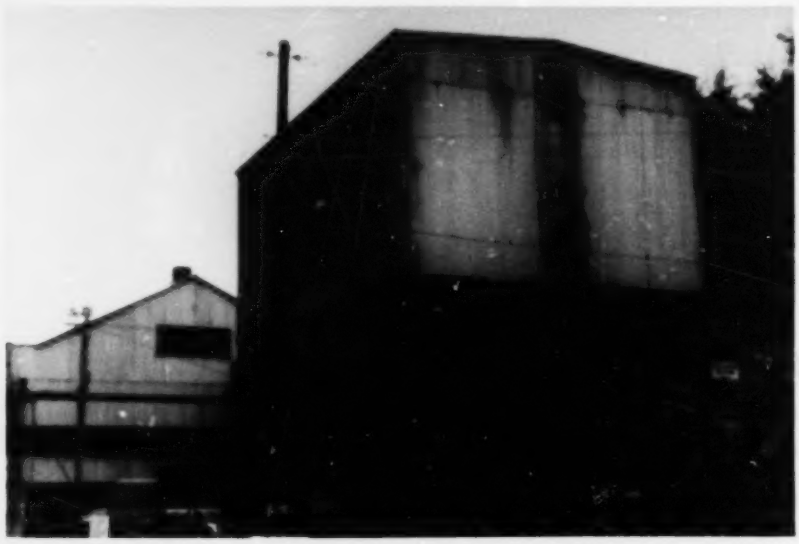

Figure 5. Baghouse with horizontal side-discharge.

Figure 6. Multistack baghouse with a peak discharge.

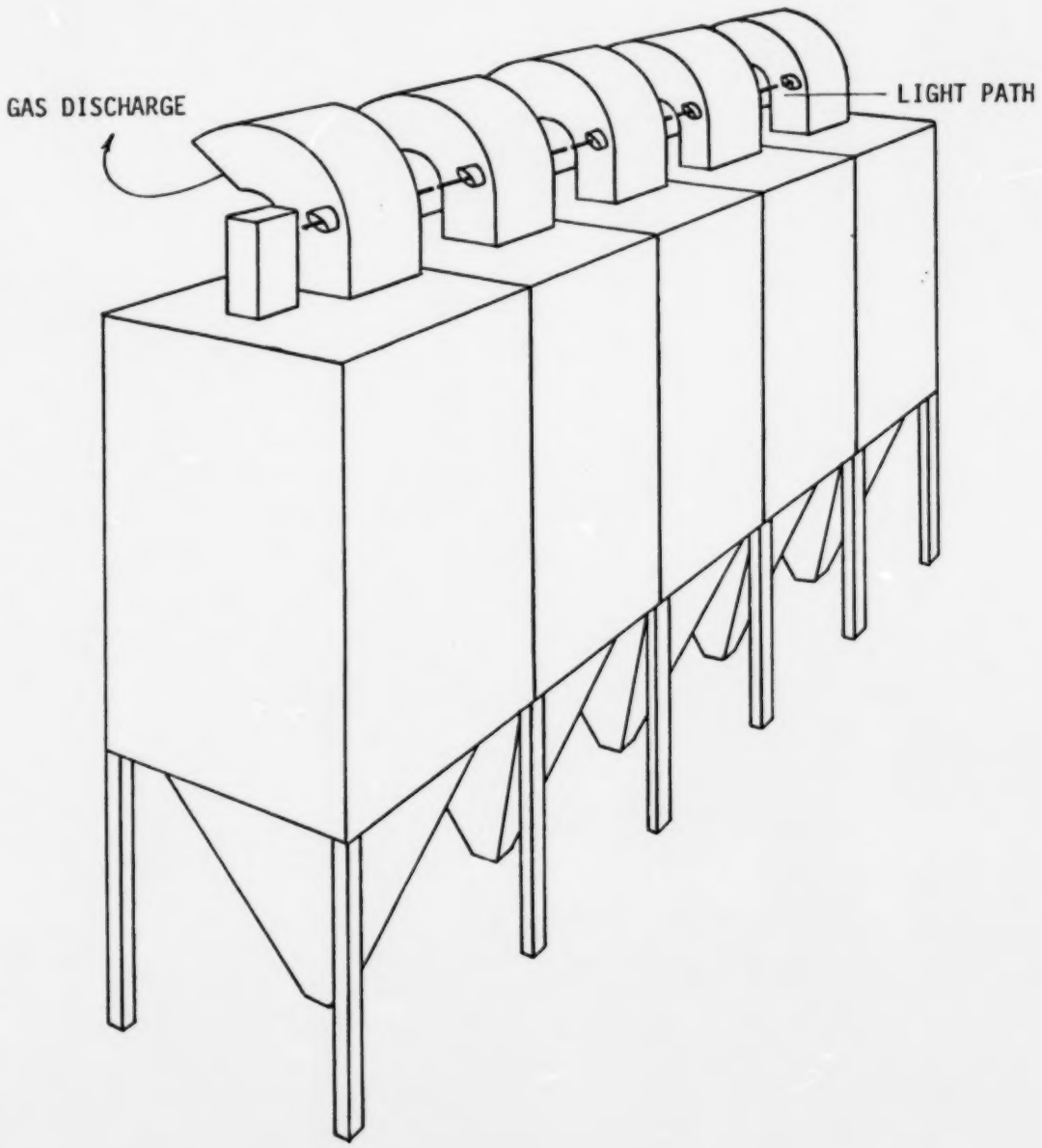

Figure 7. COM installation of multiple discharge baghouse.

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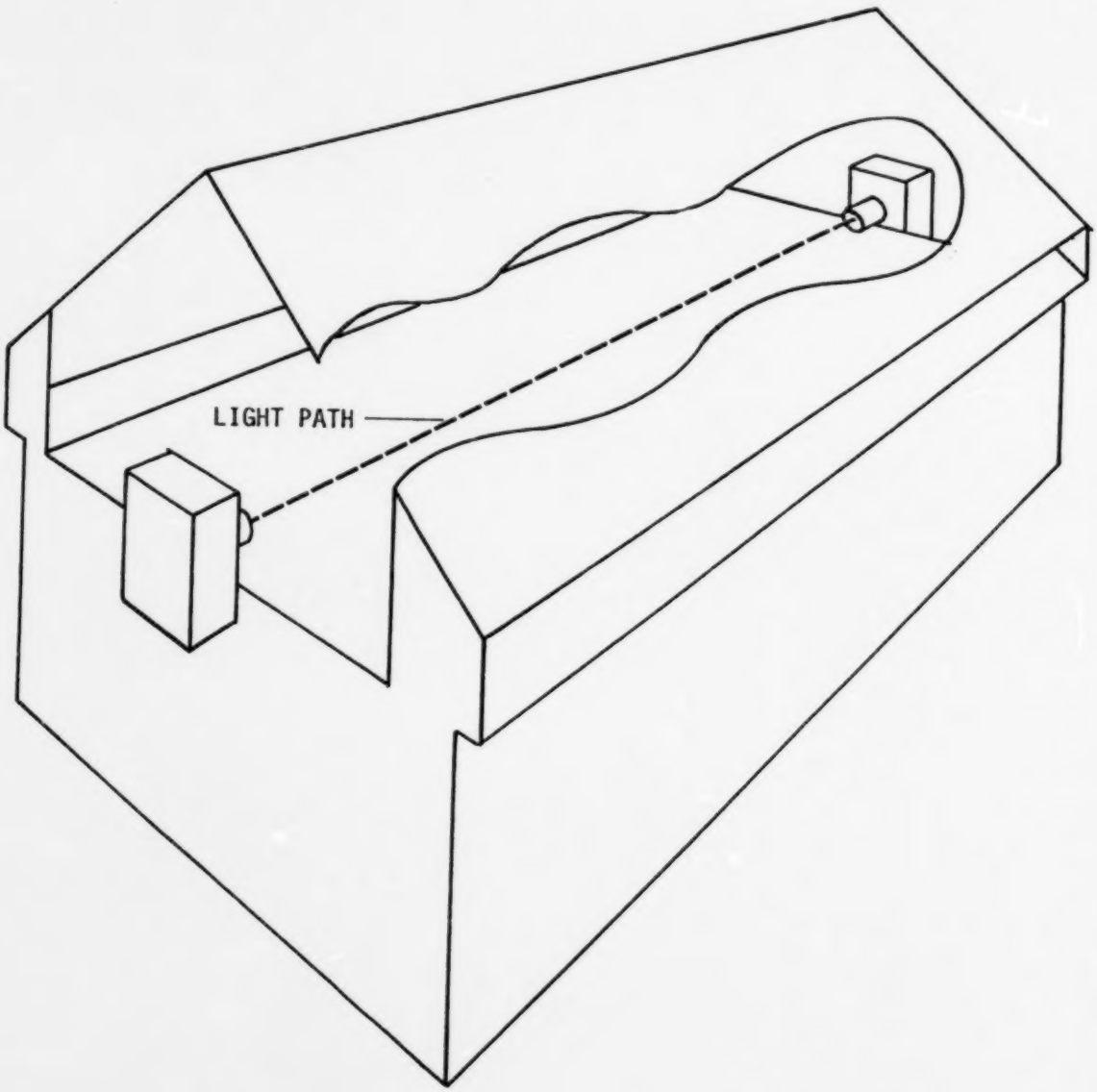

Figure 8. COM installation in an eaves-discharge baghouse.

Figure 9. Horizontal side-discharge baghouse with smoke originating near the discharge.

Figure 10. Horizontal side-discharge baghouse with smoke at the center of the cell.

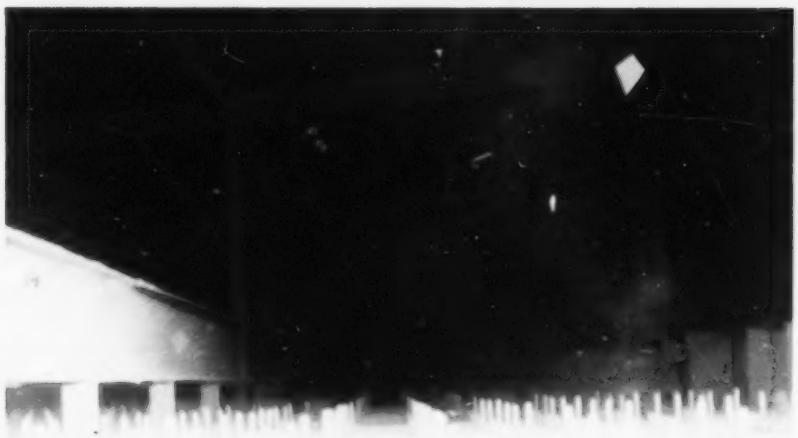

Figure 11. Horizontal side-discharge baghouse with smoke away from the discharge.

Figure 12. Smoke exiting from discharge plenum.

interrupt the COM light beam. In general, no provision is made to blend the gas stream before it reaches the COM beam, but such blending would reduce opacity of the gas stream to a level where significant failure of portions of the PB could be below the sensitivity of the COM.

Secondary problems arise from multi-stack installations, where the COM beam travels thru the atmosphere between the stacks. Here, the COM is subject to false readings due to fog, rain, and fugitive dust.

In one PB arrangement, the cell discharges face each other in a discharge plenum. This is intended to provide blending of the gas stream, but Figures 13 and 14 show that striae of gas exist for significant distances in the discharge plenum. It is not known whether the gas stream is blended by the time it reaches the discharge point. However, most baghouse designs make no provision for blending the gas stream. Although it appears possible to retrofit existing PBs' to blend the gas stream, no such device has been developed at this time.

After the gas stream has been blended, consideration might be given to monitoring techniques which are more sensitive than COM systems. One such system, which uses forward scatter of a light beam, is a photometer (nephelometer) manufactured by Sigrist Photometer A.G. of Zurich, Switzerland. This system could extract a sample of blended gas, and detect changes in particulate loading far below the 3% opacity level, thus permitting early detection and correction of PB failure.

Additional study is required, first to develop simple, inexpensive blending techniques for each type of PB, and then to demonstrate that reliable techniques are available to detect changes in particulate loading which result from reasonable baghouse failure. The first portion of the suggested study would divide existing PB installations into broad categories, and design a simple blending device for each category. Each design would be tested in the field by retrofitting an existing installation to demonstrate technical and economic feasibility of the design.

During the field tests, bag breaks could be created to compare the sensitivity of COM devices and other devices such as the photometer (nephelometer) mentioned above.

FIGURE 13

FIGURE 14

FIGURES 13 & 14: Cell discharges face each other across a common plenum.

SUMMARY

Pressurized baghouses are frequently used in large systems controlling particulate discharges because they are less expensive. Preliminary tests indicate that there is striation of the gas streams in baghouse cells, so some PB equipment failures may occur which will not be registered by COM equipment. Reliable monitoring depends on a representative gas stream passing the COM beam. But significant equipment failure can exist with indicated discharge opacity less than 3%. Many existing systems could be modified to provide gas blending. Equipment exists which can detect particulate loadings far below the 3% opacity level, but this equipment does not relate directly to opacity.

Parameters which must be met for a successful COM installation in a PB are:

- The gas stream must be blended.
- The COM beam must not exceed 100 feet,
- The COM output must be expanded so that 3% opacity covers a reasonable portion of the scale,
- Path-length corrections should be permitted only where there is a difference in measured path-length and discharge path-length, and
- The COM beam should not be affected by external climatic effects.

APPENDIX A

INSPECTIONS OF PRESSURIZED BAGHOUSES

ES

ENGINEERING-SCIENCE

7903 WESTPARK DRIVE · McLEAN, VIRGINIA 22102 · 703/790-9300

CABLE ADDRESS: ENGINSCI
TELEX: 89-9401

September 14, 1979
3122

Mr. Robert L. King
(EN-341)
U. S. Environmental Protection Agency
401 M Street, S. W.
Room 3202
Washington, D. C. 20460

Subject: Inspection of Baghouse

Dear Mr. King:

On September 6, 1979 I inspected a recently-constructed pressurized baghouse which removes particulates from air exhausted from electric arc furnaces. The site is located in Pittsburgh, Pa.

The installation, consisting of two rows of cells (six cells in one row, and five cells in the other), has been in operation for about two months. The system follows normal Wheelabrator-Frye design practice: there are large grating-covered areas on the floor which admit secondary air. The secondary air, rising by convection, may mix with gas from the bags and lower the opacity by diluting the particulate-laden gas.

Four Dynatron continuous opacity monitors are used. The light sources are mounted at the ends of the baghouses, and a pair of reflectors are mounted back-to-back at the center of each row. The output from both monitors on a baghouse row is fed into an electronic averaging device (6-minute), and the output of each averaging device is displayed on a continuous recorder. Each light path is about 85 ft. long. The top of the openings immediately above the bags is about 5 ft. wide. The monitors are mounted about a foot off the centerline. Considering the width of the opening, and the fact that the monitors are off center, it is possible that high dust loads might not be recorded by the monitor.

In summary, this recently-completed installation has two significant deficiencies:

- o Exhaust gas is diluted upstream of the monitors.
- o The monitor light path is so located that it may not see dust originating from many points in the baghouse.

Yours very truly,

ENGINEERING-SCIENCE

Theodore B. Michaelis
Air Engineering & Monitoring

TBM/rb
cc: G. Hurt
R. Neulicht

ES

ENGINEERING-SCIENCE

7903 WESTPARK DRIVE · McLEAN, VIRGINIA 22102 · 703/790-9300

CABLE ADDRESS ENGINSCI
TELEX 89-9401

December 31, 1979
3122.00/7

Mr. Robert L. King
U. S. Environmental Protection Agency
401 M Street, S. W.
Washington, D. C. 20460

Re: T. O. 62, Contract No. 68-01-4146
Trip Report

Dear Mr. King:

On November 7, 1979 the pressurized baghouse at a non-ferrous metal plant, located in central Pennsylvania, was inspected. This is a "side-discharge" baghouse, the gas exiting through louvres in one side of a cell.

Figure 1 is a plan of the baghouse, showing the two rows of four cells, each. There are no internal dividing walls in the rows of four cells, but a walkway, with walls, separates the two rows. Figure 2 is a section of the baghouse, taken at the walkway between cells. Figure 3 is an end view, showing the bag arrangement on one side. Figure 4 is a photograph of the system.

There are 20 bags to a row, 8 rows to a set, two sets in each cell. Counting the bag furthest from the gas discharge as Number 1, smoke was released adjacent to bags 2, 6, 10, 14, and 18. The smoke candle was held between rows of bags. Traverses were made releasing smoke near the floor, and about 3 feet from the top of the bags.

In all cases, it was observed that the smoke rose in distinct laminae. Smoke originating near the discharge exited at the bottom of the discharge, and smoke originating away from the discharge exited at the top. It was apparent that a beam from a continuous opacity monitor would not be affected by particulates originating from at least half the bags.

There is no location where a single continuous opacity monitor (COM) could be installed in this type of baghouse to assure accurate opacity measurement. If the particulate-bearing lamina misses the COM beam, the monitor will not register the discharge. If the particulate-bearing lamina crosses the COM beam, the monitor will register an opacity higher than the average opacity of the gas stream.

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The photographs, Figures 5 to 10, show the gas laminae in an operating baghouse. Figure 5 shows the smoke originating near the top of bag 18. The smoke remains highly concentrated, and exits at the bottom of the discharge.

Figures 6, 7, and 8 show gas originating near the top of bag 10. The distinct lamina of gas exits at the middle of the discharge louvres.

Figures 9 and 10 show gas originating at the bottom of bag 2, and Figure 9 shows the same gas exiting at the top of the discharge.

Smoke was released from many points in addition to those shown in the photographs. In every case, it was evident that flow in the baghouse was not turbulent. Gas originating furthest from the discharge rises to the top of the baghouse, and exits at the top of the louvres. Gas originating at the discharge side of the baghouse exits at the bottom of the louvers. There is no location where an opacity monitor beam could be expected to reliably measure actual gas opacity.

A monitor beam would miss high-opacity gas in most cases, and would give readings higher than the average gas opacity when the particulate-laden lamina intercepted the light beam.

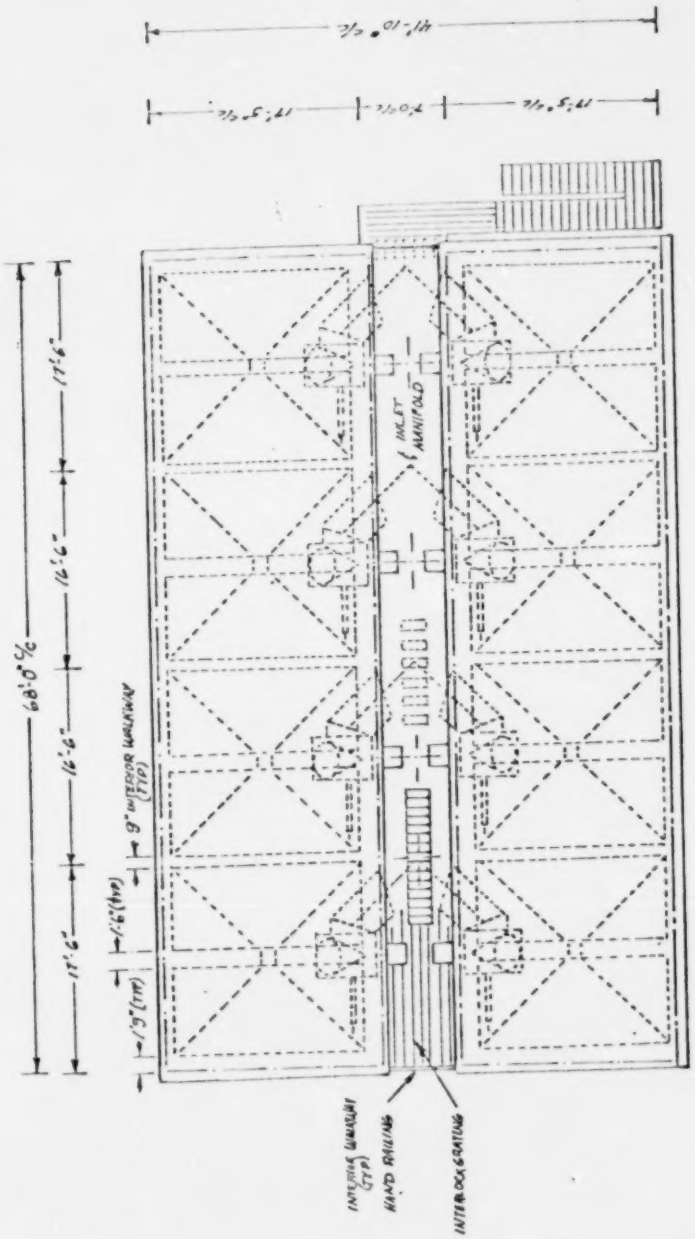
Inspections of other baghouses will be made to determine if significant differences in flow pattern can be found for different baghouse designs.

Sincerely,

ENGINEERING-SCIENCE

Theodore B. Michaelis
Air Engineering & Monitoring

TBM/rb
Encs.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17'-6"
3'-3" (typ)
7'-6" (typ)
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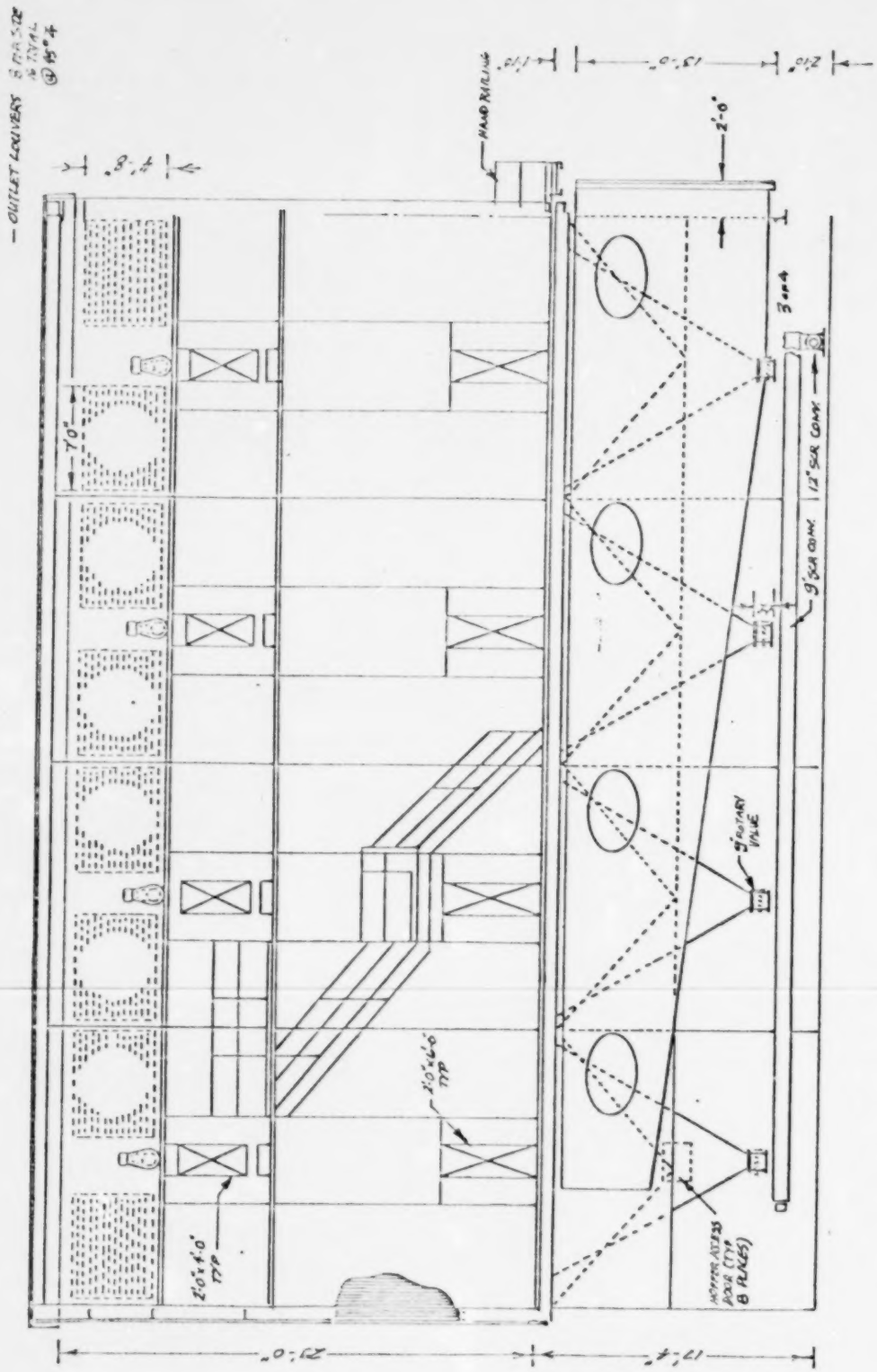
INLET MANIFOLD
INTERIOR WAVEBREAK (typ)
HAND RAILING
INTERLOCKING STATIONS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7'-0"
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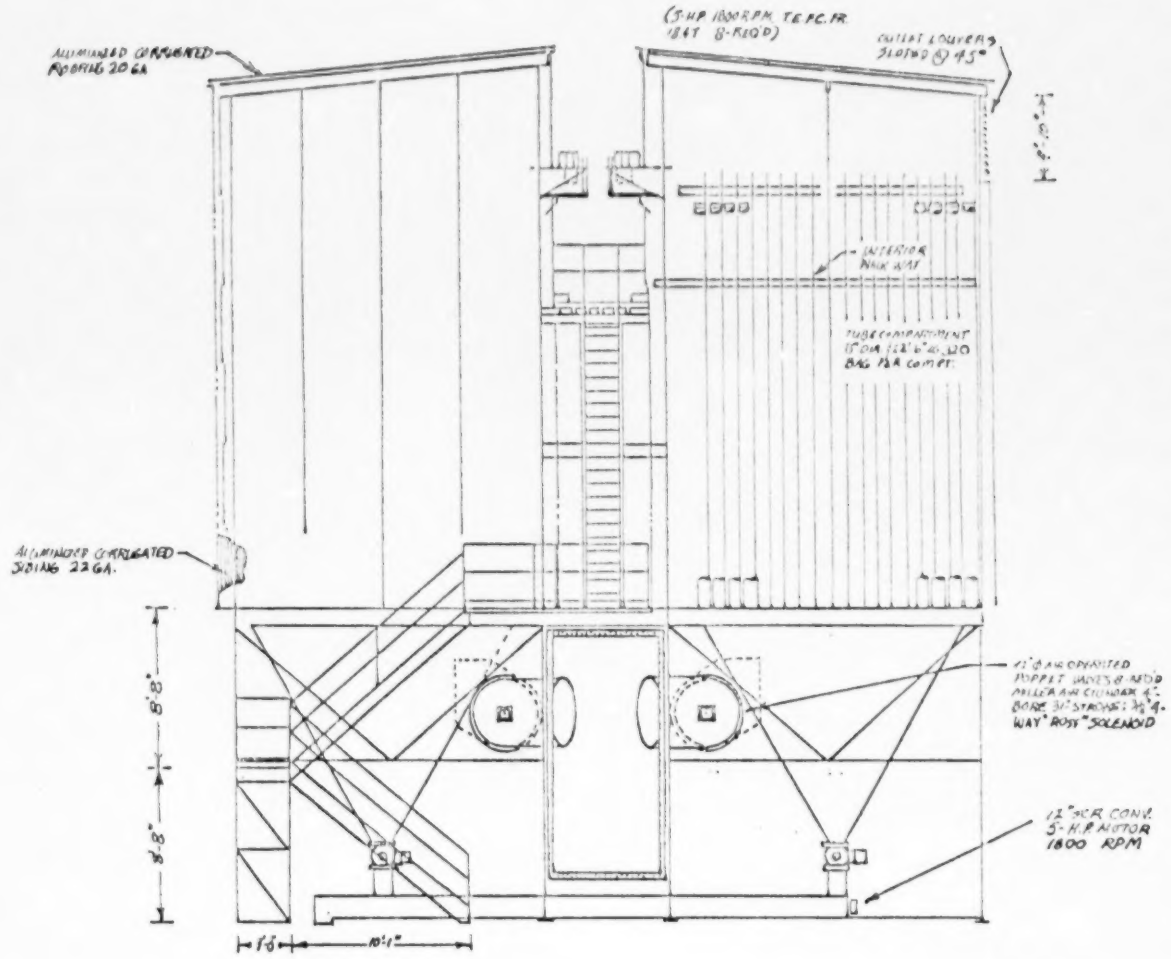
12" SCR CONV
5' ROTARY VALVE
10'x6'-0" TYP
20'x8'-0" TYP
HOPPER HEATERS (TYP 8 PLACES)
27'-0"
17'-4"


(5 HP 1800 R.P.M. T.E.P.C. FR 184T B-REQ'D)
ALUMINIZED CORRUGATED ROOFING 20 GA
OUTLET LOUVERS SLOTED @ 45°
INTERIOR PARTITION
TUBE COMPARTMENT 17" DIA. (12'6" LG. NO BAG FOR COMPT.
ALUMINIZED CORRUGATED SIDING 22 GA.
8'8"
8'8"
1'6"
10'1"
12" Ø AIR OPERATED POPPET VALVES & REQ'D PILOT AIR CYLINDER 4" BORE 3½" STROKE; ½" 4-WAY ROSS SOLENOID
12" SCR CONV. 5-H.P. MOTOR 1800 RPM

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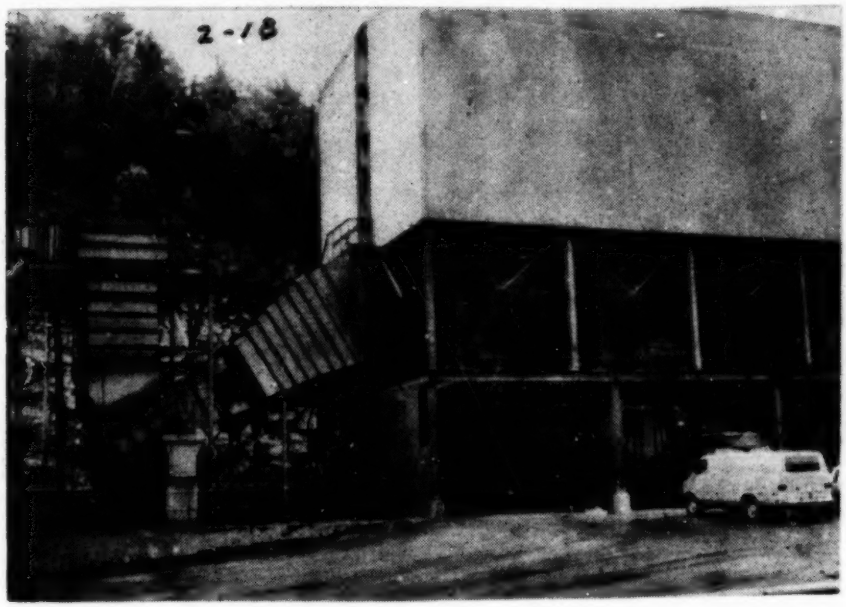


FIGURE 4

Side Discharge Baghouse

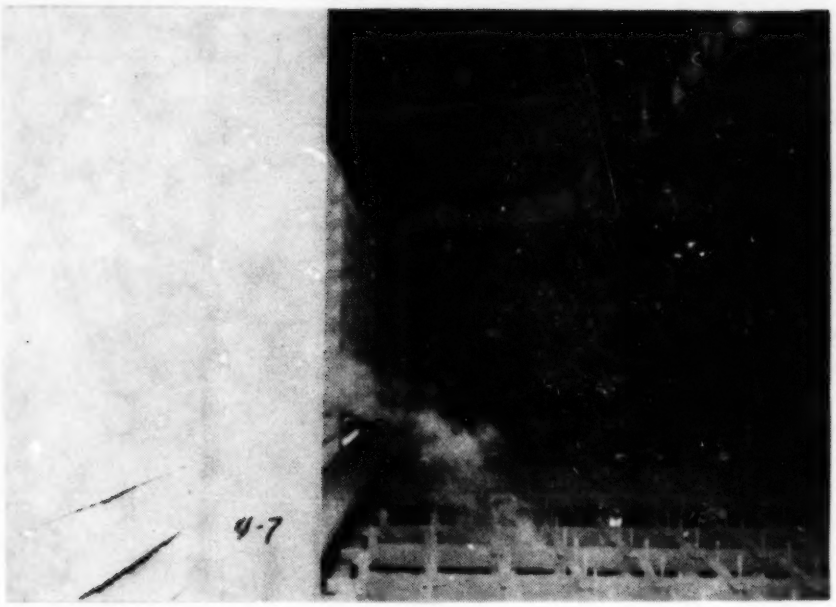


FIGURE 5

Smoke originating adjacent to bags near exit passes through bottom of louvre.

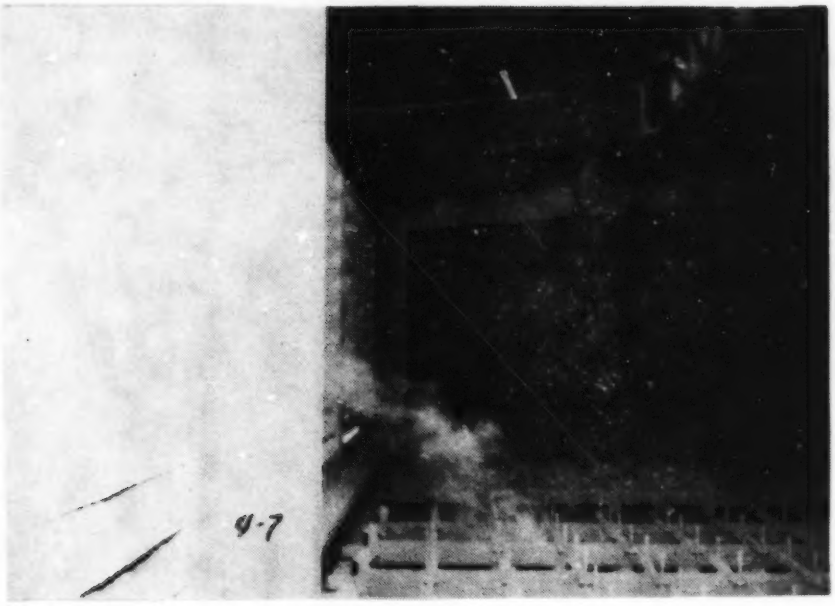


FIGURE 5

Smoke originating adjacent to bags near exit passes through bottom of louvre.

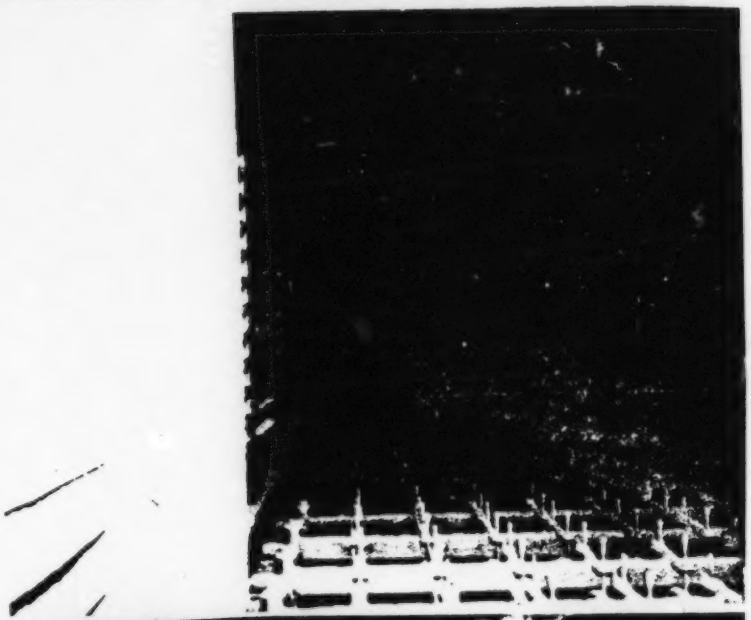


FIGURE 6

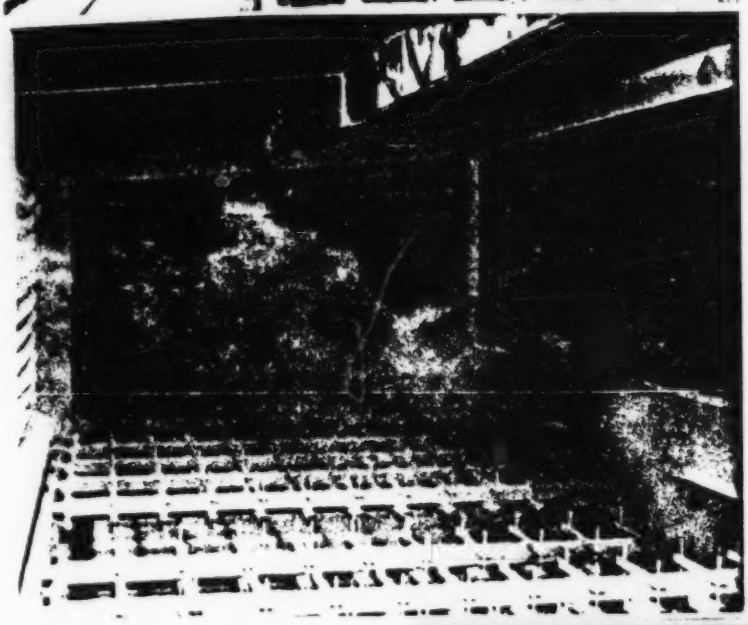
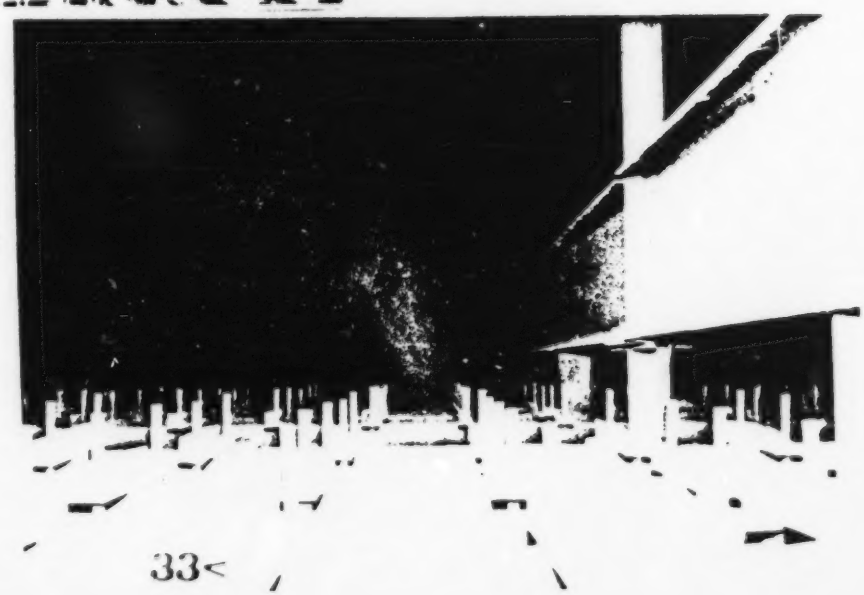


FIGURE 7

FIGURE 8

Smoke originating adjacent to bags at the center of the baghouse exits at the center of the louvres.



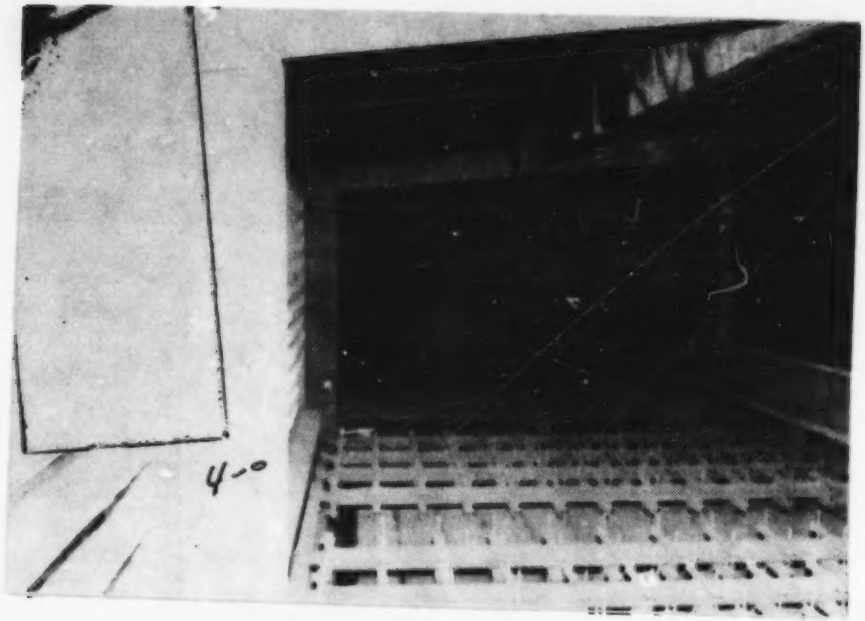


FIGURE 9

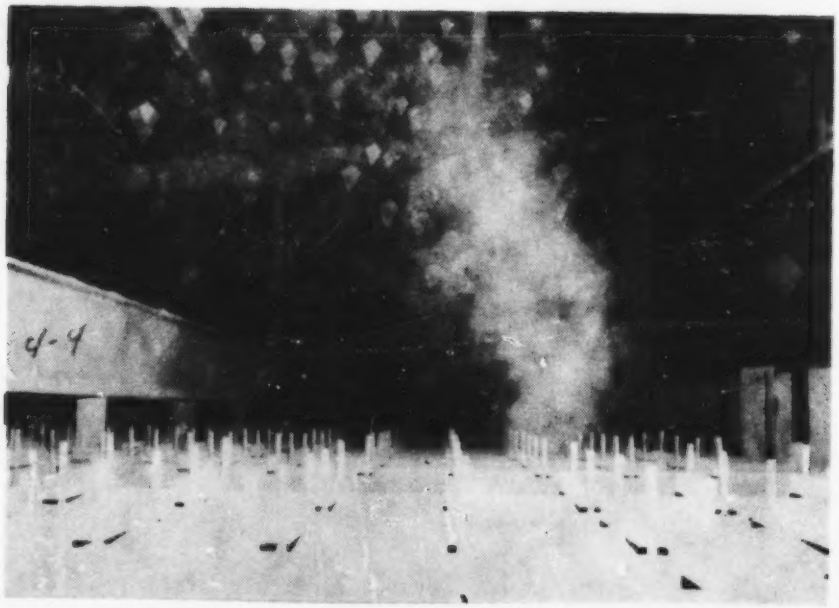


FIGURE 10

Smoke originating adjacent to bags farthest from discharge exits near top of louvres. Diamond-shaped objects on Figure 10 are due to dust on camera lens.

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7903 WESTPARK DRIVE · McLEAN, VIRGINIA 22102 · 703/790-9300

CABLE ADDRESS: ENGINSCI
TELEX 89-9401

October 16, 1979
3130.00 #12

Mr. Robert L. King
Stationary Source Enforcement Division
EN 341
401 M Street, S.W.
Washington, D.C. 20460

Re: T.O. 62, Contract 68-01-4136

Dear Mr. King:

On October 3 and 4, 1979, an operating baghouse was visited at a southern mini-steel plant. The baghouse consisted of 11 cells, each containing about 300 bags (6000 square feet in each cell). With normal gas flow in the baghouse, Smoke was released from several locations inside the baghouse, and the direction of the gas flow was noted. In all cases, there was severe lamination of the smoke in the gas stream.

The general arrangement of a single cell (without the discharge cowl) is shown in Figure 1. Figure 2 shows a plan, the bag supports, and the location where smoke was released.

Smoke released at Location 1 is shown on Figures 3 and 4. It can be seen from the photographs that the smoke is not mixed with the general gas stream. Visual observation disclosed that the smoke is confined to one corner of the discharge opening, and that this lamination continues up through the discharge. Figures 5 shows smoke released at Location 4 - about five feet above location 1. Here it is apparent that the smoke remains in one corner of the discharge.

Figure 6 shows smoke orginating from Location 5, a few feet away from location 1. Note that this smoke is slightly away from the corner of the discharge.

Figure 7 shows smoke from Location 2. This smoke touches none of the walls of the discharge cowling, but remains in a tight bundle until it is released to the atmosphere.

Figure 8 shows the smoke candle being put at Location 3. Figure 9 shows the smoke rising from the corner of the baghouse cell (Location 3), and Figure 10 shows that the smoke continues to be segregated as it passes through the discharge.

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It is apparent that particulate matter released from many places in the cell, as from a torn or ruptured bag, could pass up the discharge without being "seen" by a single beam of an opacity monitor. Even if multiple beams were used, it is probable that some possible particulate paths would be missed.

Although only one pressurized baghouse conformation has been tested, there is reason to be concerned that all pressurzied baghouses will be subject to stratification of the gas streams. We plan to test other pressurized baghouse designs, and will issue a report covering gas flow in a variety of baghouse designs.

Yours truly,

ENGINEERING-SCIENCE

Theodore B. Michaelis
Air Engineering and Monitoring

TBM/ch

cc: R. Neulicht - RTP
T. Ward - RTP
G. Hurt - Reg. V

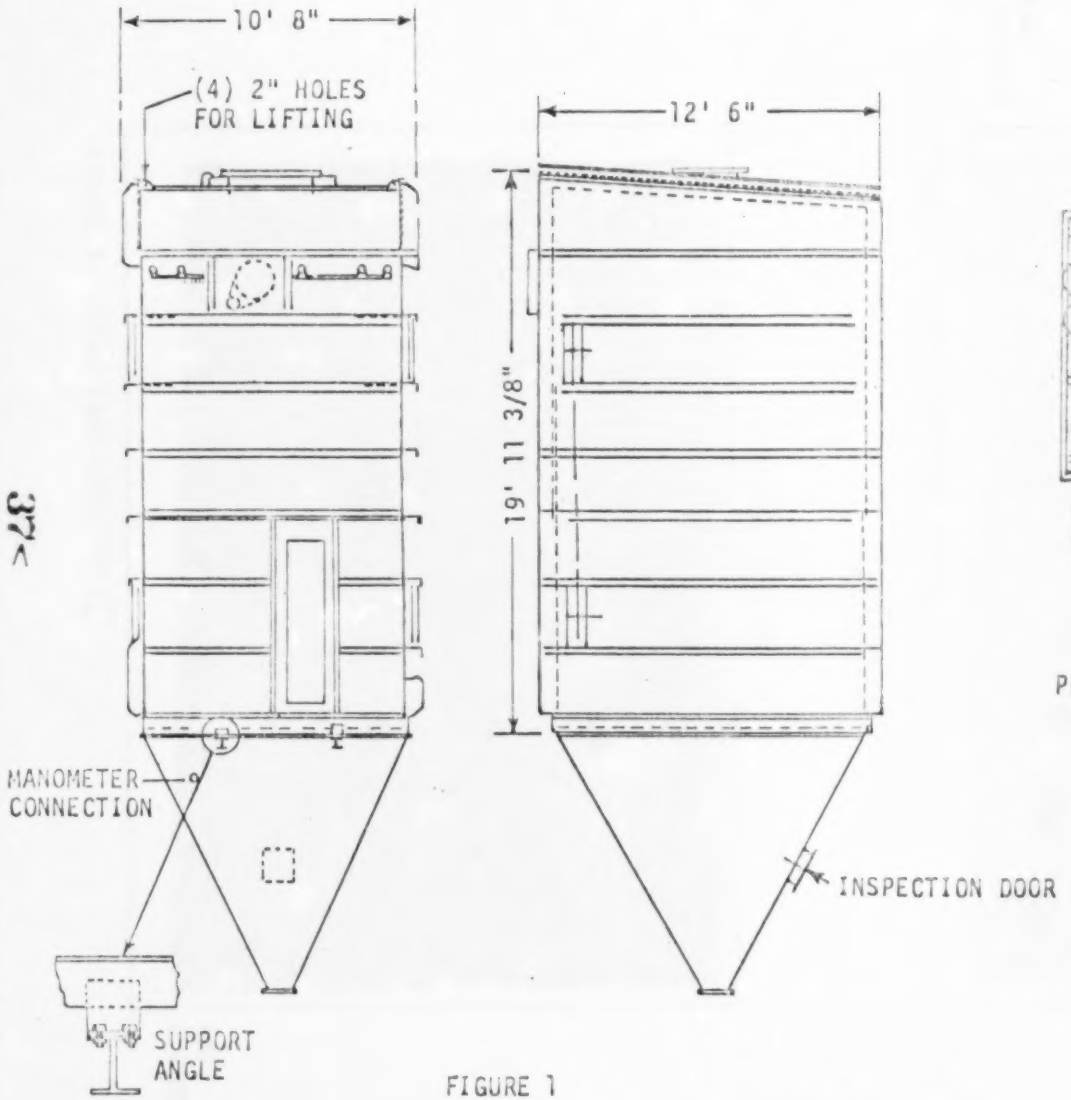


FIGURE 1

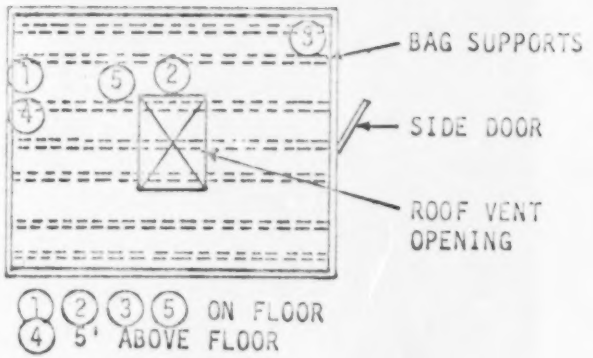


FIGURE 2

PLAN OF BAGHOUSE SHOWING SMOKE RELEASE POINTS

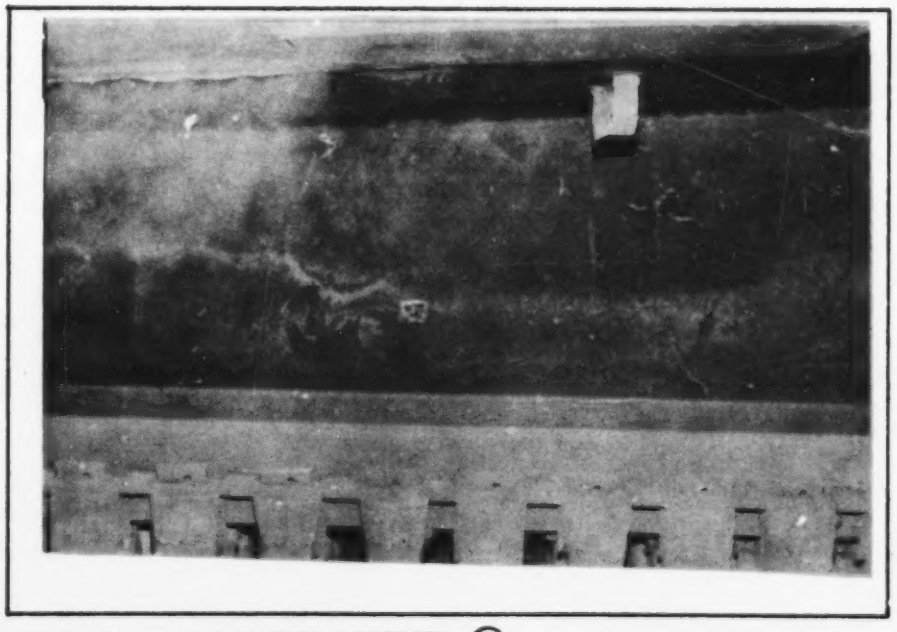
ENGINEERING-SCIENCE, INC.

DISCHARGE OPENING

BAG
SUPPORTS

FIGURE 3: SMOKE FROM LOCATION ①

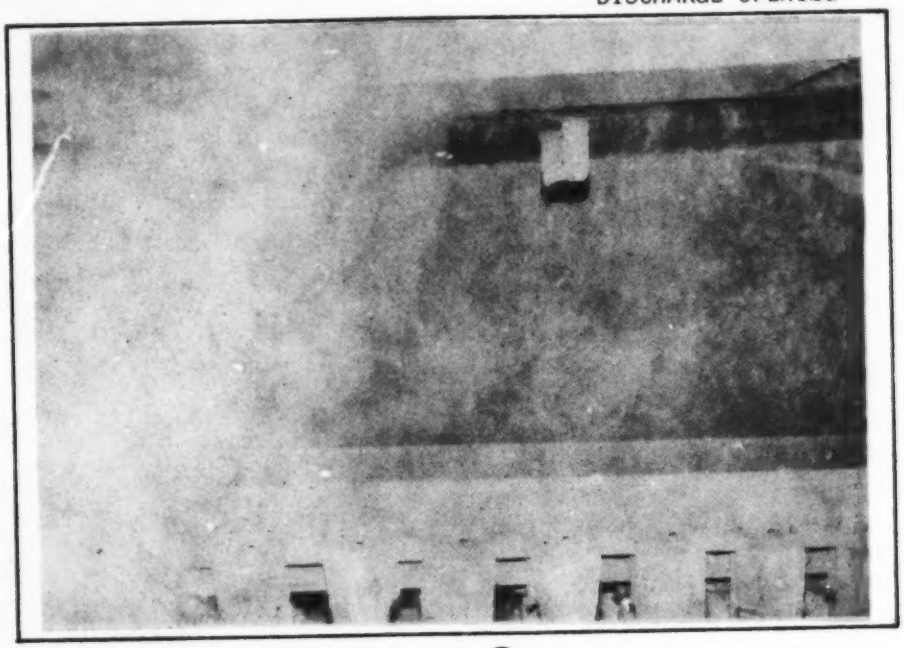
DISCHARGE OPENING



BAG
SUPPORTS

FIGURE 4: SMOKE FROM LOCATION ①

DISCHARGE OPENING



BAG SUPPORTS

FIGURE 5: SMOKE FROM LOCATION ④

DISCHARGE OPENING

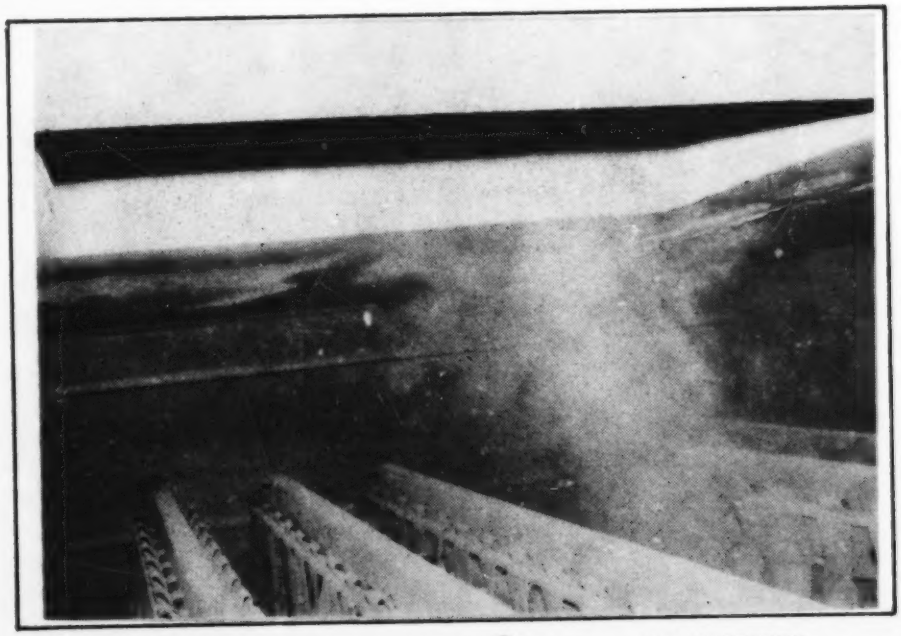


FIGURE 6: SMOKE FROM LOCATION ④ BAG SUPPORTS

DISCHARGE OPENING

BAG
SUPPORTS

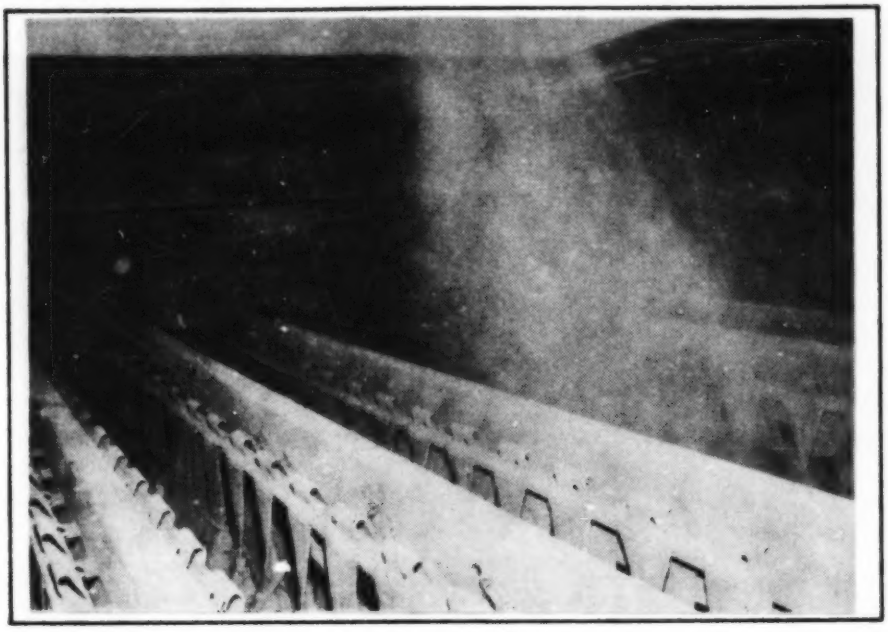


FIGURE 7: SMOKE FROM LOCATION ②

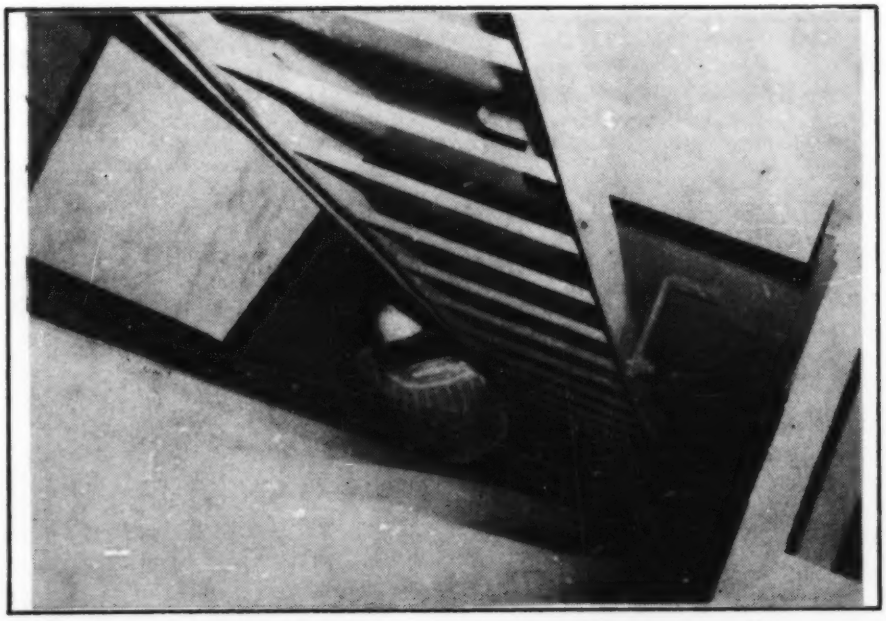


FIGURE 8: SMOKE CANDLE BEING PLACED AT LOCATION ③

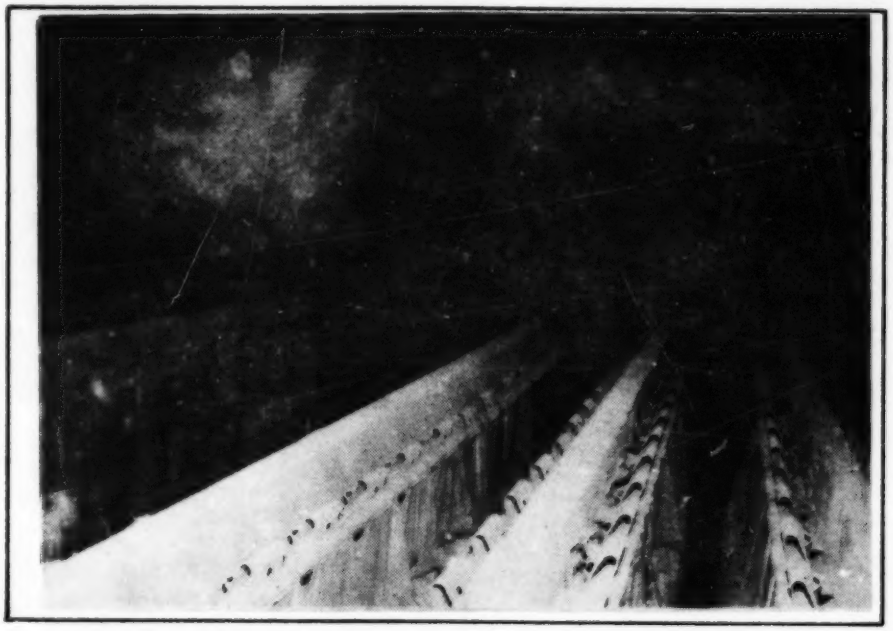


FIGURE 9: SMOKE FROM LOCATION ③
DISCHARGE OPENING NOT VISIBLE

DISCHARGE OPENING

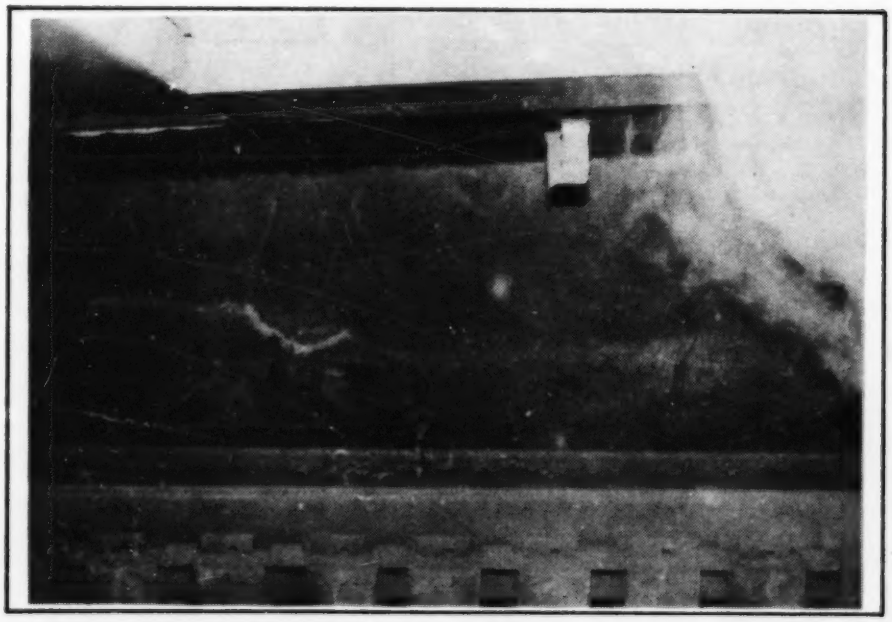


FIGURE 10: SMOKE FROM LOCATION ③